United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-343

June 1985

Natural Regeneration in Intermountain Spruce-Fir Forests—A Gradual Process

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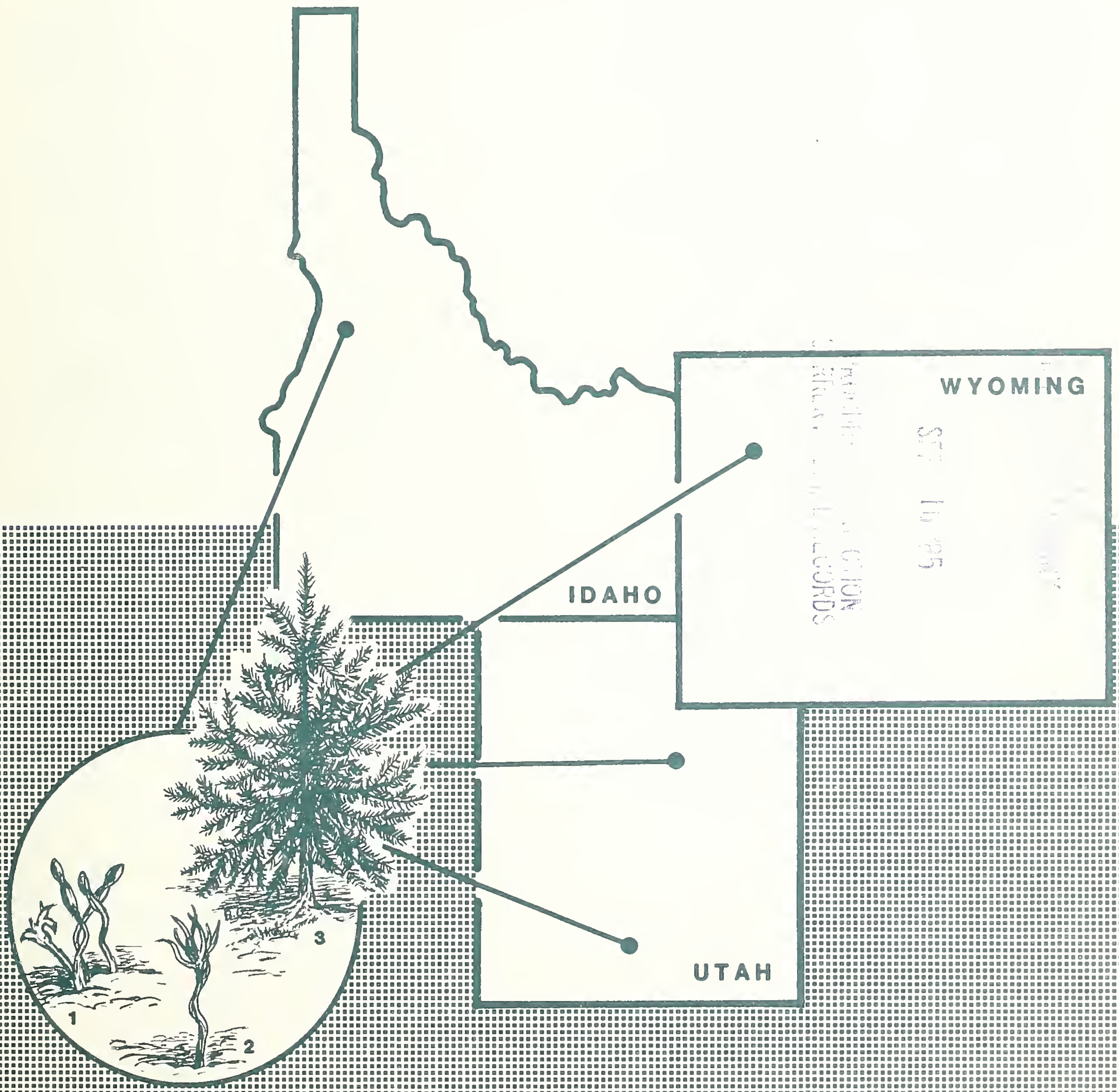

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RESEARCH SUMMARY

This study evaluated the effects of five harvest cutting-site preparation treatments on regeneration establishment in Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests of the Intermountain West. The five treatments—clearcut-scarify, clearcut-broadcast burn, clearcut-no site preparation, partial cut-scarify, and partial cut-no site preparation—were evaluated after 5 and 10 years to determine the amount and character of subsequent regeneration at four locations in Utah, Idaho, and Wyoming. In absolute terms, partial cutting treatments tended to favor the establishment of the shade-tolerant spruce and fir more than did clearcutting. Mineral soil proved more favorable for seedling establishment on the lower elevation sites in Idaho and Wyoming, while duff proved more favorable in the severe climate of high elevation sites in Utah. Even though there were many germinates, high seedling mortality throughout the 10 years resulted in relatively slow accumulation of established seedlings. For example, an average of only 10 percent of the seedlings present 5 years after harvest survived until year 10.

These results support the concept that reaching full stocking in this forest type by natural regeneration is a gradual accumulative process, and that supplemental planting will usually be needed if full stocking must be reached in a shorter time.

ACKNOWLEDGMENTS

We thank the Timber Management staff of the Forest Service Intermountain Region and the staffs of the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests for their parts in the conduct of this study. Also, we thank Arthur L. Roe (Intermountain Research Station, retired) for designing the original cutting methods trials that provided the conditions needed for this study, Dr. Robert D. Pfister (Montana Forest and Conservation Experiment Station, University of Montana) for his support and help in classifying the ecological habitat types of the study areas, Al Dahlgreen (Intermountain Region, retired) for his help in establishing and conducting the original study, Orville Engelby (Intermountain Region silviculturist) for his continuing advice and support of this study, and Joyce Schlieter (Intermountain Research Station) for statistical help in completing this paper.

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INTRODUCTION

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests blanket a major portion of the upper elevations of the Rockies. In the Intermountain section of the Rockies, this forest type comprises a large proportion of the timber resource. However, before the middle of this century, there was little harvest cutting in spruce-fir forests. Beetle (*Dendroctonus rufipennis* [Kirby]) epidemics in the 1950's caused substantial mortality in these forests, and managers responded with harvest cuttings aimed both at salvaging mortality and removing beetle-susceptible host trees. Because of the short time managers had to respond to the beetle, harvest cuts were seldom accomplished in a well-defined silvicultural framework. Many of these harvested areas failed to regenerate or were slow in regenerating.

Natural regeneration failures in these sanitation-salvage cuttings, as well as on more conventionally harvested areas, pointed out the need for more information about the regeneration processes in spruce-fir forests. Subsequent studies assessed the extent of the problem and delineated some of the apparent causes of regeneration failures. Results of these studies (Roe and Schmidt 1964; Roe and others 1970) pointed out the importance of seedbed, local environment, and seed supply in determining the ultimate success or failure of natural regeneration in this forest type. The factors associated with this triumvirate needed to be built into a silvicultural framework that could be tested. This need prompted the U.S. Department of Agriculture, Forest Service, Intermountain Region and Intermountain Research Station to enter into a joint study effort aimed at determining the long-term effects of several combinations of harvest cutting and site preparation methods on natural seedling establishment. To make the results as applicable as possible, the study was established on four widely separated areas of the Intermountain Region—the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests.

The primary objectives of this study, started in 1967, were to:

1. Evaluate the growth response of advance understory trees to release following clearcutting and partial cutting.
2. Evaluate the effects of five harvest cutting-site preparation treatments on natural regeneration establishment.

McCaughey and Schmidt (1982) reported the results of the first objective. This paper reports the results of the second objective based on the 5-year and 10-year remeasurements of the four study areas.

METHODS

Five harvest cutting-site preparation treatments, with two replications, were installed on each of four study areas in 1967. The overall study design was a 4 × 5 factorial, with two replications per cell.

Source of variation	Degrees of freedom
Forests	3
Treatments	4
Interaction (forests × treatments)	12
Error	20
Total	39

The five treatments were:

1. Clearcutting with dozer scarification (CCS)
2. Clearcutting with broadcast burning (CCB)
3. Clearcutting with no site preparation (CCO)
4. Partial cutting with dozer scarification (PCS)
5. Partial cutting with no site preparation (PCO)

Each treatment was applied to two rectangular (10- by 20-ch) 5-acre units for a total of 10 treatment units per study area. Twenty 1-milacre regeneration plots (6.6 by 6.6 ft) were established in each treatment unit for a total of 40 plots per treatment. Ten plots were randomly established in each 5-acre unit by superimposing a grid over the treatment unit map and randomly selecting coordinate pairs (fig. 1). Because randomly established plots did not always represent the assigned site preparation treatment, a second plot was subjectively located on the closest representative seedbed to each random plot. For example, on treatment units receiving dozer scarification, subjectively located plots were established on the closest area of mineral soil large enough to accommodate a milacre plot.

Seedling numbers were recorded by species in two categories—first-year seedlings and 2-year and older

PLOT NO.	AXIS X	AXIS Y
1	5	14
2	3	6
3	2	18
4	9	17
5	8	9
6	2	13
7	7	3
8	4	18
9	2	4
10	5	9

NOTE X & Y VALUES ARE FROM RANDOM NUMBER GENERATOR

R - RANDOMLY LOCATED PLOT

S - SUBJECTIVELY LOCATED PLOT

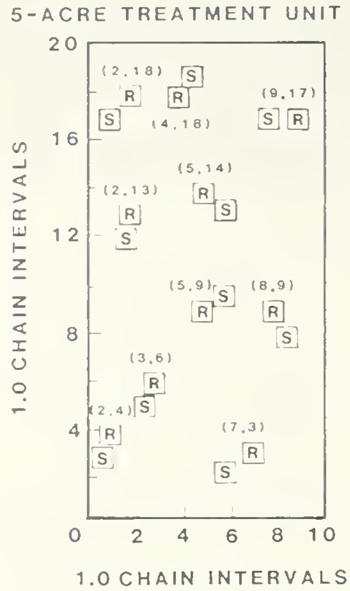

Figure 1.—Schematic example of a treatment unit map illustrating milacre plot locations.

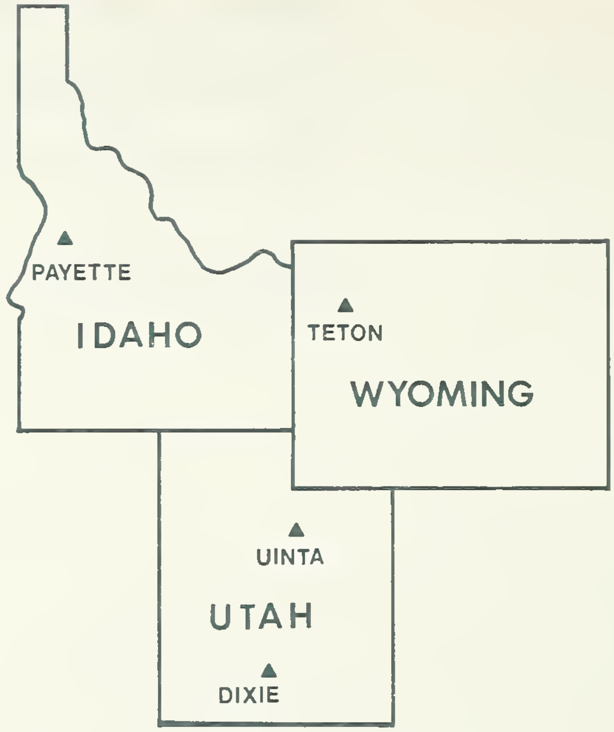

Figure 2.—Location of spruce-fir natural regeneration study areas in the Intermountain West: Payette, Teton, Uinta, and Dixie National Forests.

seedlings—for each plot 5 and 10 years after treatment. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, the number of 5-year and older seedlings was recorded for each plot at year 10 only. Each plot was also classified as to habitat type and seedbed surface.

Study Areas

The overall study area extended approximately 425 north-south air miles from southern Utah to south-central Idaho and 325 east-west air miles from south-central Idaho to western Wyoming. The four study areas were located on the Payette National Forest in Idaho, the Teton National Forest in Wyoming, the Uinta National Forest in central Utah, and the Dixie National Forest in southern Utah (fig. 2).

Payette National Forest.—The Payette study area is near Cloochman Creek on the McCall Ranger District, about 6,000 ft elevation with a west to southwest exposure. Slopes range from 0 to 30 percent and average around 10 percent.

Soils are generally sandy loams of granitic origin, moderately to well drained, and slightly acid. Some of the cutting units are bisected by small streams and contain boggy areas.

Composition (by volume) of the virgin stand was 77 percent Engelmann spruce, 18 percent subalpine fir, and 5 percent lodgepole pine (*Pinus contorta* Dougl. ex Loud.). The mature stand was over 200 years old at the time of cutting.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
129.0	29.0	7.0

Individual point samples ranged from 0 to 250 ft^2 of basal area per acre. Remaining basal area within the clearcuts was due to residual advance regeneration. Partial cut treatments were individual tree selection cuts.

Three habitat types (h.t.'s) are represented on the area (Steele and others 1981):

Dry	-	*Abies lasiocarpa/Xerophyllum tenax* h.t., mostly *Vaccinium scoparium* phase.
Moist	-	*Abies lasiocarpa/Xerophyllum tenax* h.t., mostly *Vaccinium globulare* phase.
Wet	-	*Abies lasiocarpa/Calamagrostis canadensis* h.t., *Ligusticum canbyi* phase.

Teton National Forest.—The Teton study area is in Teton County, WY, near East Leidy Creek on the Gros Ventre Ranger District at approximately 8,600 ft elevation. The study area faces north and ranges in slope from 0 to 50 percent, with occasional pitches to 70 percent.

Soils are derived from Mesozoic sedimentary rock—primarily limestone, sandstone, and shale. Moisture is adequate at all times of the year, and some areas have excessive soil moisture for ideal growing conditions, as evidenced by the increase of *Equisetum*. Drainage of the area varies from poor to good.

The Teton has the largest variety of species found on any of the study areas. Stand composition (by volume) at the time of harvest was 85 percent Engelmann spruce, 8 percent subalpine fir, 3 percent lodgepole, 3 percent limber pine (*Pinus flexilis* James), and 1 percent Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco).

Stand age of the mature overwood at the time of cutting was between 200 and 300 years old. The general stand condition was good, with only minor bark beetle problems in some of the windthrown spruce.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
132.0	82.0	1.0

Individual point samples ranged from 0 to 280 ft^2 of basal area per acre. The clearcut basal area value was due to residual advance regeneration. Partial cut treatments were individual tree selection cuts.

Three habitat types were mapped on the study site (Steele and others 1983):

Dry - *Abies lasiocarpa/Vaccinium globulare* h.t.
Moist - *Abies lasiocarpa/Actaea rubra* h.t.
Wet - *Abies lasiocarpa/Streptopus amplexifolius* h.t.

Uinta National Forest.—The Uinta National Forest study area is in Wasatch County, UT, on the Heber Ranger District. The plots are on a northerly aspect at 9,500 ft elevation, with slopes ranging from 10 to 30 percent.

Soils are generally well drained on the upper slopes, with soil moisture increasing toward the base of the study area. Small intermittent streams bisect the area.

Stand composition (by volume) was 95 percent Engelmann spruce and 5 percent subalpine fir. General stand condition was good with minimal windthrow and light bark beetle damage.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
146.0	109.0	42.0

Individual point samples ranged from 0 to 230 ft^2 of basal area per acre. The large basal area value in the clearcuts was due to advance regeneration left on the site. Partial cut treatments were group selection cuts; that is, small half-acre clearcuts scattered throughout the 5-acre treatment block.

One habitat type was found on the area—*Abies lasiocarpa/Berberis repens* h.t., *Berberis* phase (Pfister 1972).

Dixie National Forest.—The Dixie study units are in Garfield County, UT, on the Aquarius Plateau of the Escalante Ranger District at 10,300 ft elevation on nearly level terrain.

Soils are glacial deposits overlaying basalt flows. Soils are gravelly, clay, and sandy loams, 12 to 21 inches deep, with pH values of 5 to 6.

Stand composition (by volume) of the mature forest was 90 percent Engelmann spruce, 10 percent subalpine fir, and a few small scattered aspen (*Populus tremuloides* Michx.) clones. Overstory Engelmann spruce were all-aged, while subalpine fir were uneven-aged but not all-aged (Hanley and others 1975). General condition of the mature stand was good, but many snags indicated past beetle attacks. Recent bark beetle activity was light.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
141.0	40.0	6.0

Individual point samples ranged from 0 to 210 ft^2 of basal area per acre. Advance regeneration accounted for the clearcut basal area. Partial cut treatments were group selection cuts; that is, small half-acre clearcuts scattered throughout the 5-acre treatment block.

One habitat type, *Abies lasiocarpa/Ribes montigenum* h.t., *Ribes* phase (Pfister 1972), was found on the study area.

Treatment Establishment

The original intent of the study was that harvest and site preparation on each of the four forests would be accomplished the same year, 1967. However, because of weather and other problems, some exceptions to the original schedule occurred:

Payette—Burning was unsuccessful in November 1967; it was completed in September 1968.

Uinta—Three scarification treatments were completed in 1968 and one in July 1969.

Dixie—All units scheduled for burning were completed in fall 1968, a year after logging.

Otherwise, all treatments were completed in 1967.

Data Analysis

We described natural regeneration establishment with percentage milacre stocking and seedling density per acre. Stocking and density of seedlings 2 years of age and older are compared between treatments and within treatments for the 5-year and 10-year periods after harvest. First-year seedlings were not included because of the extremely high mortality rate in this age class (Noble and Alexander 1977; Alexander 1984). Because 5-year-old seedlings in spruce-fir forests are considered established from the standpoint of environmental factors (Noble and Ronco 1978), stocking and density of seedlings 5 years of age and older were also compared between treatments for the 10-year postharvest measurement.

Wide variability in both stocking levels and seedling counts made data transformation necessary before analysis could proceed. Because stocking is expressed as a proportion (percent), the arcsin transformation was selected to stabilize the variance. The transformation $\sqrt{\text{density} + 1}$ was used to stabilize variance of density data. This particular form of the square root transformation was chosen because some seedling counts were zero (Snedecor and Cochran 1967).

Initially, pooled data from all forests were analyzed to determine if stocking and density varied significantly between forests. Analysis of variance methods showed both stocking and density varied significantly ($\alpha = 0.05$) between forests. Therefore, further analysis was conducted on a forest-by-forest basis.

The following techniques were used to analyze natural regeneration data from individual forests.

Stocking: The test for binomial proportions was used to analyze within-treatment changes in stocking from the fifth to the 10th year after harvest. Stocking between treatments and stocking of random versus subjective plots were also compared using this technique.

Density: The Student's t-test was used to analyze within-treatment changes in seedling density from the fifth to the 10th year after harvest. This method was also employed to test density between treatments and between randomly and subjectively located plots. An approximate t-test was used in cases where variances were unequal.

RESULTS AND DISCUSSION

Results of this study provide insight into the post-harvest natural regeneration of high-elevation spruce-fir forests and help explain the frustration experienced by many managers in this forest type. The "wave" of natural regeneration that often follows harvest in lodgepole pine, ponderosa pine, and western larch forests is not a common phenomenon in these spruce-fir forests. Instead, a slow accumulation of surviving seedlings appears the normal pattern of restocking on cutover areas. The following sections describe this process in the framework of different silvicultural treatments for the first 10 years after harvesting.

Stocking—Between Treatments

Data were analyzed in terms of two age classes of seedlings.

Seedlings 2 Years and Older.—Only one consistent treatment-stocking pattern was discernible. In absolute terms, milacre stocking was highest on the partial cut with no site preparation (PCO) treatment on all forests 5 and 10 years after harvest (table 1). The relatively high stocking levels on the PCO treatment were unexpected. Intermittent shade and mitigation of temperature and moisture extremes provided by the partial overstory may have offset the widely reported superiority of scarified seedbeds over duff for seedling establishment. Statistical evaluation showed milacre stocking was highly variable between treatments on all forests. Comparisons of stocking between treatments are shown in table 1.

Seedlings 5 Years and Older.—A more realistic assessment of stocking, based on seedlings 5 years and older, showed few significant differences ($\alpha = 0.05$) between treatments 10 years after harvest. Stocking of 5-year

Table 1.—Milacre plot stocking of 2-year and older seedlings 5 and 10 years after harvest, and 5-year and older seedlings 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

		Years since harvest		
		5	10	10
National Forest	Harvest cutting-site preparation treatment	2-year and older seedlings	2-year and older seedlings	5-year and older seedlings
		Percent milacre stocking[1]		
Payette	CCS: Clearcut-scarify	42 ab	52 kl	21 tu
	CCB: Clearcut-broadcast burn	25 b	50 l	12 tu
	CCO: Clearcut-no site preparation	38 ab	52 l	14 u
	PCS: Partial cut-scarify	46 ab	77 jk	30 t
	PCO: Partial cut-no site preparation	50 a	84 j	16 tu
Teton	CCS: Clearcut-scarify	18 cd	67 mn	5 vw
	CCB: Clearcut-broadcast burn	20 cd	72 mn	5 vw
	CCO: Clearcut-no site preparation	12 d	52 n	10 v
	PCS: Partial cut-scarify	20 cd	52 n	0 w
	PCO: Partial cut-no site preparation	32 c	78 m	18 v
Uinta	CCS: Clearcut-scarify	18 ef	35 pq	0 x
	CCB: Clearcut-broadcast burn	12 ef	49 op	8 x
	CCO: Clearcut-no site preparation	8 f	23 q	3 x
	PCS: Partial cut-scarify	10 ef	34 pq	0 x
	PCO: Partial cut-no site preparation	25 e	58 o	5 x
Dixie	CCS: Clearcut-scarify	8 hi	10 rs	5 y
	CCB: Clearcut-broadcast burn	2 i	3 s	3 y
	CCO: Clearcut-no site preparation	15 h	18 r	10 y
	PCS: Partial cut-scarify	15 h	9 rs	6 y
	PCO: Partial cut-no site preparation	35 g	23 r	15 y

[1]Treatment stocking values within a forest, sharing a common letter within a column, are not significantly different ($\alpha = 0.05$).

and older seedlings was usually much lower than, but proportional to, 10-year postharvest stocking of 2-year and older seedlings by treatment and forest (table 1).

Density—Between Treatments

Data were analyzed in terms of two age classes of seedlings.

Seedlings 2 Years and Older.—The number of 2-year and older seedlings varied widely between some treatments on every forest, yet few of these differences were significant at the $\alpha = 0.05$ level (table 2). Lack of significance between treatments where density differences appear large was due to extreme variability between samples.

The treatment supporting the highest absolute density of seedlings 2 years and older changed from year 5 to year 10 on each forest, and was different for all forests 10 years after harvest. Lack of density trends either by year or forest indicates the volatility in natural regeneration when measured in terms of seedlings less than 5 years old. Treatments with the highest density 5 and 10 years after harvest were:

	5 years	10 years
Payette National Forest	CCS	PCS
Teton National Forest	PCO	CCB
Uinta National Forest	CCS	PCO
Dixie National Forest	PCO	CCO

Seedlings 5 Years and Older.—Evaluation of the number of established seedlings, 5 years and older, provides a less optimistic view of regeneration density. Only 17, 24, 13, and 46 percent, respectively, of the 2-year and older seedlings present at year 5 on the Payette, Teton, Uinta, and Dixie National Forests survived to year 10. Even though the number of established seedlings was low, density levels varied widely between some treatments on every forest (table 2). However, in only one case were density levels significantly different ($\alpha = 0.05$) between treatments (PCO and PCS treatments on the Teton National Forest). The general lack of significance

Table 2.—Seedling density of 2-year and older seedlings 5 and 10 years after harvest, and 5-year and older seedlings 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Harvest cutting-site preparation treatment	Years since harvest: 5 — 2-year and older seedlings	10 — 2-year and older seedlings	10 — 5-year and older seedlings
		Seedlings per acre[1]		
Payette	CCS: Clearcut-scarify	5,848 a	7,581 g	742 n
	CCB: Clearcut-broadcast burn	1,678 a	3,062 g	188 n
	CCO: Clearcut-no site preparation	3,676 a	6,355 g	258 n
	PCS: Partial cut-scarify	2,371 a	7,486 g	800 n
	PCO: Partial cut-no site preparation	2,425 a	5,757 g	594 n
Teton	CCS: Clearcut-scarify	225 b	10,077 h	154 op
	CCB: Clearcut-broadcast burn	250 b	14,025 h	50 op
	CCO: Clearcut-no site preparation	250 b	4,575 h	175 op
	PCS: Partial cut-scarify	375 b	7,750 h	0 p
	PCO: Partial cut-no site preparation	525 b	9,725 h	175 o
Uinta	CCS: Clearcut-scarify	425 cd	486 jk	0 q
	CCB: Clearcut-broadcast burn	150 cd	1,595 i	81 q
	CCO: Clearcut-no site preparation	100 d	333 k	26 q
	PCS: Partial cut-scarify	375 cd	921 ij	0 q
	PCO: Partial cut-no site preparation	375 c	1,737 i	79 q
Dixie	CCS: Clearcut-scarify	175 ef	250 lm	50 r
	CCB: Clearcut-broadcast burn	25 f	29 m	29 r
	CCO: Clearcut-no site preparation	525 e	550 l	62 r
	PCS: Partial cut-scarify	231 ef	121 lm	75 r
	PCO: Partial cut-no site preparation	900 e	513 l	342 r

[1]Treatment seedling density values within a forest sharing a common letter within a column are not significantly different ($\alpha = 0.05$).

(α = 0.05) in density levels between treatments was due to wide variability in seedling numbers between samples.

In absolute terms, treatments with the highest densities of 5-year and older seedlings were:

Payette National Forest	PCS
Teton National Forest	PCO, CCO
Uinta National Forest	CCB
Dixie National Forest	PCO

Stocking—Within Treatments

Stocking showed a definite upward trend with increasing time since harvest on all forests except the Dixie. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, within-treatment stocking comparisons from the fifth to the 10th year after harvest were made for 2-year and older seedlings only. Milacre stocking increased in absolute terms from the fifth to the 10th year for all treatments on the Payette, Teton, and Uinta National Forests (fig. 3). Stocking increases were significant on the partial cut treatments on the Payette, all treatments on the Teton, and the CCB and partial cut treatments on the Uinta National Forest.

The stocking trend on the Dixie differed noticeably from the other three forests. Milacre stocking remained stable or declined from year 5 to year 10 on all treatments, though none of the changes were significant at the α = 0.05 level. Low initial stocking at year 5, with only minor within-treatment stocking changes by year 10, attests to the severe, high elevation regeneration environment on this forest.

Density—Within Treatments

Seedling density increased substantially with increasing time since harvest on all study areas except the Dixie. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, within-treatment comparisons of density from the fifth to the 10th year were confined to 2-year and older seedlings. Density increased in absolute terms from year 5 to year 10 for all treatments on the Payette, Teton, and Uinta National Forests (fig. 4). These increases were significant (α = 0.05) on the partial cut treatments on the Payette, all treatments on the Teton, and the CCB and PCO treatments on the Uinta National Forest.

In contrast, density by treatment changed little or declined relative to time since harvest on the Dixie National Forest. Seedling density from the fifth to the 10th year after harvest increased slightly on the clearcut treatments and declined moderately on the partial cut treatments on this forest, though none of the changes were significant (α = 0.05). Lack of significant increases in density at year 10 from initially low levels at year 5 reflects the inherent difficulty of establishing natural regeneration above 10,000 ft on the Dixie.

Stocking-Density Relationships

Seedling density was significantly correlated (α = 0.05) to milacre stocking on all forests 10 years after

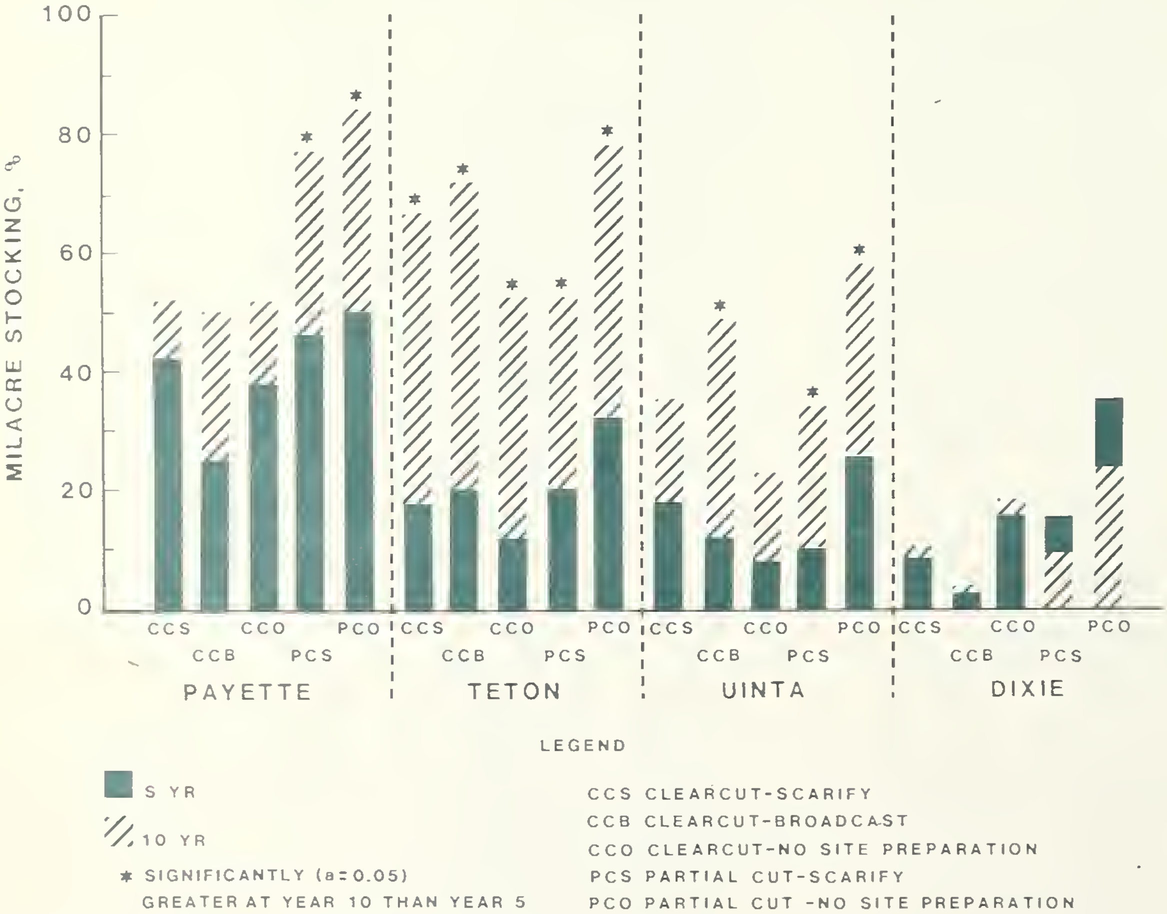

Figure 3.—A comparison of milacre stocking of 2-year and older seedlings 5 and 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests.

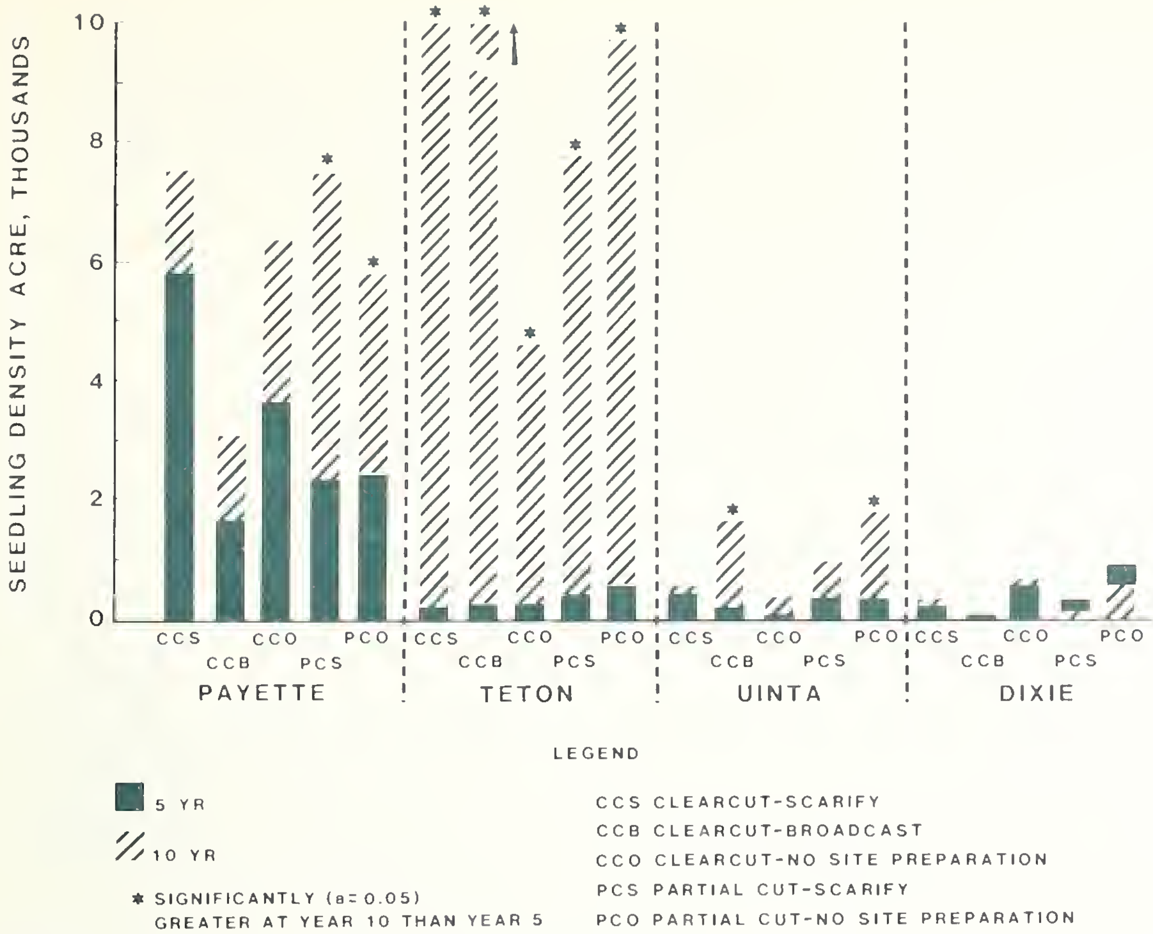

Figure 4.—A comparison of seedling density per acre of 2-year and older seedlings 5 and 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests.

harvest. A quadratic function best fit the combined stocking-density data for established (5-year and older) seedlings on all forests 10 years after harvest (fig. 5). Density varied directly with stocking, but at an increasing rate at higher stocking levels. Similar relationships between density and stocking have been reported by Harris (1967) and Seidel (1979).

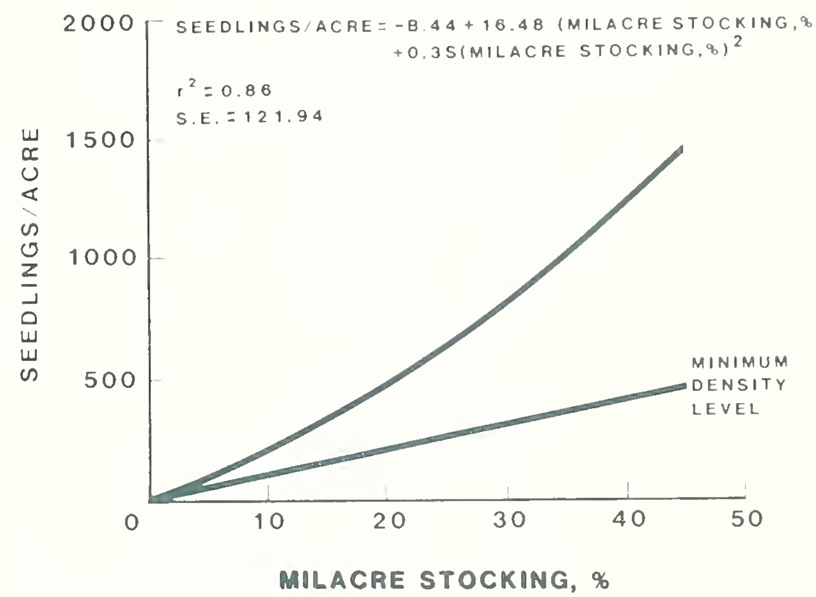

Figure 5.—Relationship of milacre stocking percent to seedling density per acre for 5-year and older seedlings on the Payette, Teton, Uinta, and Dixie National Forests. The minimum density line represents the stocking-density relationship if there was only one seedling on each stocked milacre plot.

Seedling Survival

The ratio of 5-year and older seedlings at year 10 to the total number of seedlings (age 1 to 4 years) present 5 years after harvest varied considerably between forests but averaged 10 percent for the four forests combined. While this study was not designed to assess causes of seedling mortality, low overall survival quantifies the extreme attrition rate of young seedlings in spruce-fir forests.

The survival rate of seedlings present 5 years after harvest to year 10 was 2 percent on the Teton, 7 percent on the Uinta, 18 percent on the Payette, and 41 percent on the Dixie National Forest. The survival rate was lowest on the Teton, the area with the highest seedling density at year 5, and highest on the Dixie, the area with the lowest initial density. This apparent disparity indicates that the few seedlings present 5 years after harvest in the harsh environment above 10,000 ft on the Dixie were on microsites that favored survival, and thus, nearly half (41 percent) lived to year 10. In contrast, the moist-to-wet conditions prevalent over much of the Teton study area provided a favorable medium for seedling germination. However, inundation and trampling destroyed a high proportion of these seedlings. A high water table resulting from overstory removal on the wet *Abies lasiocarpa/Streptopus amplexifolius* h.t. (ABLA/STAM) (Steele and others 1983) and heavy moose (*Alces alces*) activity associated with the moist *Abies lasiocarpa/Actaea rubra* h.t. (ABLA/ACRU) were major causes of mortality on the Teton.

Because site preparation within treatments was never totally accomplished, regeneration data for each of the five treatments were compared between 20 randomly located plots representing the average of the site treatment and 20 subjectively located plots representing the actual (assigned) treatment. For example, random plot locations on broadcast burn treatments usually fell on burned seedbed but occasionally on unburned duff or mineral soil, while subjectively located plots were always installed on burned seedbed.

Milacre stocking of 5-year and older (established) seedlings did not vary significantly ($\alpha = 0.05$) between the average of the site treatment and actual seedbed surface for any treatment on any forest (table 3). Density of established seedlings also did not vary significantly between actual and average seedbed conditions for any treatment/forest combination (table 4).

Distinct differences have been reported in regeneration of spruce and fir on different seedbeds (Muri 1955; Smith 1955; Roe and Schmidt 1964). Engelmann spruce germinates best on mineral soil seedbeds (U.S. Department of Agriculture 1948; Fiedler 1976). Barr (1930) noted that mineral soil generally loses moisture less rapidly than duff with seasonal drying, resulting in higher spruce germination and lower drought losses. Furthermore, Daniel and Glatzel (1966) found duff seedbeds could be lethal to overwintering Engelmann spruce seeds. Subalpine fir also regenerates well on mineral seedbeds, but because fir has greater first-year root elongation than spruce, it is better equipped to survive on duff surfaces (Smith 1955; Day 1964; Eis 1965).

We also examined regeneration by species in relation to actual seedbed surface to determine if the species-seedbed relationships reported above hold for these Intermountain sites. To do this, we pooled regeneration data from each forest on the basis of actual seedbed surface—that is, mineral, burned, or duff—regardless of treatment. We then calculated stocking and density for Engelmann spruce and subalpine fir on mineral, burned, and duff seedbeds.

Regeneration by species varied not only by seedbed but also by location and elevation. Relative stocking success of both Engelmann spruce and subalpine fir varied inversely with elevation on mineral seedbeds and directly with elevation on duff seedbeds. Stocking levels

Table 3.—Milacre plot stocking of 5-year and older seedlings on randomly located plots representing the average site treatment and on subjectively located plots representing the actual prescribed treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Cutting method	Scarification		Broadcast burn		No site preparation	
		Average	Actual	Average	Actual	Average	Actual
		Percent					
Payette	Clearcut	17	31	0	25	5	17
	Partial cut	22	35	—	—	10	22
Teton	Clearcut	5	5	0	10	5	15
	Partial cut	0	0	—	—	20	15
Uinta	Clearcut	0	0	5	11	0	5
	Partial cut	0	0	—	—	5	5
Dixie	Clearcut	5	5	6	0	15	5
	Partial cut	12	0	—	—	10	20

Table 4.—Seedling density of 5-year and older seedlings on randomly located plots representing the average site treatment and on subjectively located plots representing the actual prescribed treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Cutting method	Scarification		Broadcast burn		No site preparation	
		Average	Actual	Average	Actual	Average	Actual
		Seedlings per acre					
Payette	Clearcut	611	923	0	375	105	500
	Partial cut	277	1,353	—	—	158	1,056
Teton	Clearcut	250	53	0	100	50	300
	Partial cut	0	0	—	—	200	150
Uinta	Clearcut	0	0	53	111	0	53
	Partial cut	0	0	—	—	53	105
Dixie	Clearcut	50	50	59	0	400	300
	Partial cut	118	0	—	—	105	550

of both spruce and fir were sharply higher on mineral than on duff seedbeds on the 6,000-ft Payette site, somewhat higher on the 8,600-ft Teton site, slightly lower on the 9,500-ft Uinta site, and similar for spruce and much lower for fir on the 10,300-ft Dixie site (table 5). This elevational gradient is directly correlated with the geographic north-south locations of the four study sites. The gradual shift in relative stocking success from mineral to duff seedbeds with increasing elevation is logical when examined in light of changes in seedling environment that accompany changes in elevation.

While both spruce and fir germinate well on mineral seedbeds, duff possesses several advantages over mineral seedbeds for seedling survival at higher elevations. Duff lessens the impact of frequent, high-intensity summer storms that can wash out or bury young seedlings. Rainstorms with intensities of up to 8 inches per hour have been reported in Utah's mountains—severe enough to cause surface erosion problems (Croft and Marston 1950). Duff also provides protection from frost heaving, a common phenomenon on high elevation mineral seedbeds before snow cover in the fall and after snowmelt in the spring. Noble and Alexander (1977) reported that frost heaving accounted for 3 to 27 percent of total seedling mortality on mineral seedbeds but caused no mortality on duff seedbeds above 10,000 ft in Colorado's spruce-fir zone.

Seedling density/seedbed relationships by species followed a pattern similar to stocking. Densities of both Engelmann spruce and subalpine fir were higher on mineral than on duff seedbeds at lower elevations, with a transition to higher relative densities on duff seedbeds at high elevations (table 6).

The regeneration advantage reported for subalpine fir over Engelmann spruce on duff seedbeds was not evident in this study. Studies in the Canadian, northern, and central Rockies have reported drought as a major cause of spruce seedling mortality on duff seedbeds. Drought was also reported as a major cause of spruce mortality in another regeneration study on the Dixie National Forest (Hanley and Pfister 1983). However, Roe and Schmidt (1964) reported that moisture generally did not appear critical to seedling survival in the Intermountain spruce-fir zone.

Burned seedbed conditions apparently ameliorated over time on the less severe sites and became increasingly favorable for seedling establishment. In absolute terms, stocking and density of both Engelmann spruce and subalpine fir were lowest on burned seedbeds on all forests 5 years after treatment (tables 5 and 6). However, spruce stocking and density increased dramatically on burned seedbeds by year 10 on the Payette, Teton, and Uinta, and fir increased on the Payette and Teton National Forests. Fiedler (1980) found similar sharp increases in regeneration with increasing time since treatment on burned seedbeds in the spruce-fir zone of Montana.

Table 5.—Milacre plot stocking of 2-year and older seedlings by species, seedbed, and time since treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Species	Time since treatment	Mineral seedbed	Burn seedbed	Duff seedbed
		Years	*Percent*		
Payette	Engelmann spruce	5	47	7	13
		10	64	36	40
	Subalpine fir	5	46	0	21
		10	68	18	33
	All	5	56	7	23
		10	76	41	50
Teton	Engelmann spruce	5	12	4	10
		10	60	80	44
	Subalpine fir	5	10	4	9
		10	19	36	14
	All	5	20	4	18
		10	63	92	44
Uinta	Engelmann spruce	5	14	8	14
		10	33	59	37
	Subalpine fir	5	5	0	7
		10	3	0	4
	All	5	14	8	18
		10	34	59	37
Dixie	Engelmann spruce	5	6	0	10
		10	6	0	5
	Subalpine fir	5	4	0	15
		10	2	0	15
	All	5	10	0	21
		10	6	0	18

Table 6.—Seedling density of 2-year and older seedlings by species, seedbed, and time since treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Species	Time since treatment	Mineral seedbed	Burn seedbed	Duff seedbed
		Years	*-----------Seedlings*	*per acre-----------*	
Payette	Engelmann spruce	5	3,218	74	645
		10	5,842	1,454	1,404
	Subalpine fir	5	1.942	0	500
		10	3,842	227	788
	All	5	5.160	74	1,145
		10	9,684	1,682	2,192
Teton	Engelmann spruce	5	178	120	158
		10	8,060	25,280	2,965
	Subalpine fir	5	144	40	105
		10	402	560	210
	All	5	322	160	263
		10	8,462	25,840	3,175
Uinta	Engelmann spruce	5	231	100	339
		10	700	2.054	750
	Subalpine fir	5	48	0	89
		10	40	0	38
	All	5	279	100	428
		10	740	2,054	788
Dixie	Engelmann spruce	5	154	0	127
		10	174	0	61
	Subalpine fir	5	58	0	407
		10	43	0	351
	All	5	212	0	534
		10	217	0	412

Ten years after treatment, subalpine fir was absent on burned seedbeds on the Uinta National Forest, and both spruce and fir were absent on burned surfaces on the Dixie. Establishment difficulties on burned seedbeds were apparently greater and more persistent on these high elevation Utah sites.

Engelmann spruce stocking and density increased sharply on all seedbeds from the fifth to the 10th year after treatment on the Payette, Teton, and Uinta National Forests. Fir stocking and density also increased on all seedbeds on the Payette and Teton, though increases were less than for spruce.

SUMMARY

Results of this study are generally consistent with findings of other studies of regeneration in the subalpine zone. We found, along with Noble and Ronco (1978) in Colorado, Fiedler (1980) in Montana, and Minore and Dubrasich (1981) in Oregon, that natural regeneration is a slow process following harvest cutting in subalpine forests.

Although the number of germinates was high in this study, especially on the Payette and Teton, few seedlings survived the first growing season, and fewer yet reached age 5. If the age criterion of 5 years is used to define an established seedling (Noble and Ronco 1978), stocking and density levels were low on all treatments and forests 10 years after harvest. Overall, only 10 percent of the seedlings (age 1 to 4 years) present 5 years after harvest survived to year 10. This highlights the extreme attrition rate in these forests and the extended regeneration period needed to reach full stocking.

Examination of regeneration by species in relation to actual seedbed surface, regardless of treatment, revealed several relationships:

1. Regeneration of both Engelmann spruce and subalpine fir was higher on mineral than duff seedbeds at lower elevations, with a gradual transition to higher relative stocking levels on duff seedbeds at higher elevations. This shift was attributed to the seedling survival advantages of duff seedbeds at high elevations, namely, insulation from frost heaving and protection from surface erosion caused by high-intensity summer storms.

2. In contrast to other studies, we found subalpine fir had no distinct regeneration advantage over Engelmann spruce on duff seedbeds. Regeneration studies in other sections of the Rockies have reported spruce more drought susceptible than fir on duff seedbeds, though Roe and Schmidt (1964) found that moisture was generally not critical to seedling establishment in the geographical area covered by this study.

3. Regeneration in absolute terms was lowest on burned seedbeds at all locations 5 years after harvest but increased dramatically by year 10 on all forests

except the Dixie. Seedling establishment difficulties on burned seedbeds were greater and longer lasting on the high elevation Utah forests. Ten years after harvest, fir was still missing from burned seedbeds on the Uinta, and both Engelmann spruce and subalpine fir were absent on burned seedbeds on the Dixie.

We were unable through this study to identify a preferred harvest cutting-site preparation prescription for securing regeneration on any forest. However, we did find that the pattern of regeneration was not the same at all locations. On the Payette, Teton, and Uinta, stocking and density of 2-year and older seedlings increased substantially in absolute terms from the fifth to the 10th year after harvest, in spite of high seedling mortality rates (that is, less than 10 percent of the seedlings present at year 5 on these forests survived to year 10). In contrast, initially low stocking and density levels on the Dixie changed little from the fifth to the 10th year after harvest. Yet nearly half of the small number of seedlings present at the 5-year measurement on this forest survived to year 10.

Germination and early survival were moderately to sharply higher and percent survival to year 10 somewhat lower on the three northern forests than on the Dixie. Though germination and early seedling survival patterns varied between the four forests, regeneration status in terms of established (5-year and older) seedlings did not differ greatly at year 10. Because of the high mortality rate of young seedlings on all forests, we believe distribution and number of 5-year and older seedlings, rather than 2- to 4-year-old seedlings, provide a more realistic basis for describing and comparing the regeneration status of these sites. On this basis, stocking and density levels were highest on the Payette, intermediate on the Teton and Dixie, and lowest on the Uinta.

While the overall regeneration picture is gradually improving, stocking and density of established seedlings were still at low levels on all study areas 10 years after harvest. If extended regeneration periods are not compatible with management objectives, planting will be necessary to augment the gradual natural restocking that typifies these high elevation Intermountain forests.

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This paper describes the natural regeneration process for 10 years following five harvest cutting-site preparation treatments in spruce-fir forests of Idaho, Utah, and Wyoming. High seedling mortality throughout the period resulted in slow accumulation of established seedlings on all treatments.

KEYWORDS: *Picea engelmannii, Abies lasiocarpa*, natural regeneration, harvest cutting, site preparation

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